no action

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: June 16, 1976

Project Title: Doctoral Research Program - Aircraft Structures

Project No: E-19-648

Project Director: E. A. Starke, Jr.

Sponsor: Lockheed-Georgia Company

Agreement Period: From 6/1/76 Until ~~5/31/78~~ 7/31/78

Type Agreement: Purchase Order No. CN36774

Amount: $16,000

Reports Required: Quarterly Letter Reports
Final Report

Sponsor Contact Person (s):

Technical Matters

Mr. W. R. Britton, Buyer
Dept. 52-25, Zone 383
LOCKHEED-GEORGIA COMPANY
Marietta, Georgia 30063

Contractual Matters
(thru OCA)

Defense Priority Rating:

Assigned to: Chemical Engineering (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
Accounting Office
Procurement Office
Security Coordinator (OCA) ✓
Reports Coordinator (OCA)

Library, Technical Reports Section
Office of Computing Services
Director, Physical Plant
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other ______

CA-3 (3/76)

8

no action req'd

GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 11/10/78

OAH

Project Title: Doctoral Research Program - Aircraft Structures

Project No: E-19-648

Project Director: Dr. E. A. Starke

Sponsor: Lockheed-Georgia Co.

Effective Termination Date: 7/31/78

Clearance of Accounting Charges: 7/31/78

Grant/Contract Closeout Actions Remaining:

x Final Invoice ~~and Closing Documents~~

_ Final Fiscal Report

_ Final Report of Inventions

_ Govt. Property Inventory & Related Certificate

_ Classified Material Certificate

_ Other ______________________

Assigned to: Aerospace Engineering (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
Accounting Office
Procurement Office
Security Coordinator (OCA) ✓
Reports Coordinator (OCA)

Library, Technical Reports Section
Office of Computing Services
Director, Physical Plant
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other ______________________

E-19-648

DOCTORAL RESEARCH PROGRAM-AIRCRAFT STRUCTURES
LOCKHEED-GEORGIA COMPANY CONTRACT CN36774

First Quarterly Status Report
September 1, 1976

1. The generally poor fatigue properties displayed by 7XXX aluminum alloys are often attributed to microstructural influences which promote localized deformation during cyclic loading. Conventionally used commercial ingot processing methods for these alloys produce highly elongated and partially-recrystallized grain structures which result in directional properties. Fatigue deformation in such materials is shown to be concentrated in larger recrystallized grains, rather than distributed uniformly throughout the microstructure. The application of intermediate thermomechanical treatments (ITMT) to 7XXX alloys to produce fine, equiaxed grain structures offers the possibility for improving fatigue resistance by eliminating the inhomogeneous fatigue deformation occurring in commercially-processed material. Our initial efforts have concentrated on comparing the cyclic stress strain response of commercially processed, CP, 7050 with that of ITMT 7050. The CP material was kindly supplied by the Alcoa Technical Center, and the ITMT material by Dr. Jeffery Waldman of Frankford Arsenal.

2. Quantitative optical metallography has been performed to characterize the grain size and shape of the differently processed materials. The parameters obtained will be used for correlation with low cycle fatigue and crack propagation parameters. Low cycle fatigue tests have been completed on CP and ITMT materials aged to the T6X1 condition. This represents maximum strength for alloy 7050 and is obtained by solutionizing at 890°F for 3 hrs., followed by aging 4 hrs at 250°F and 4 hrs at 335°F. The total strain range covered was from 1.0% to 2.2% which corresponded to a plastic strain of 0.12% to 1%.

   Cyclic softening was observed during the early stages of testing for both materials and for all strain amplitudes. This was attributed to the removal of residual stresses that were induced during quenching, rather than to resolution of precipitates. The cyclic stress strain curves have been determined and were found to be initially below the monotonic curves for both the CP and ITMT material. The cyclic work hardening exponent, n', was slightly larger for the ITMT material, and this may be related to its more homogenous deformation characteristics. Strain amplitude-life (Coffin-Manson) plots predict a better fatigue resistance for the ITMT material at long lives, (low strain amplitudes); however, at very high strain amplitudes the Coffin-Manson curve for the CP material predicts a better fatigue resistance. This is probably related to the higher fracture toughness of the CP 7050. Hot rolled ITMT 7050, which has a fracture toughness as high as CP 7050, will be tested in the near future.

   In order to establish the relationship between grain structure and crack initiation, some samples were polished and examined during various stages of the fatigue life. For the CP material, cracks were observed to start at grain boundaries, slip bands and inclusions. For the ITMT material cracks initiated almost exclusively at grain boundaries. The mechanisms which produce this difference has not yet been established.

3. During the next quarter we will concentrate on measuring fatigue crack growth, FCG, of the CP and ITMT 7050 aged to the T6X1 condition. The data obtained from the monotonic, CSSR, and FCG will be correlated with the microstructural features and deformation modes of the various materials to establish their relationships. In addition, the various theories which use CSSR data to predict FCG will be critically examined.

Submitted by,

E. A. Starke, Jr.
Project Director

DOCTORAL RESEARCH PROGRAM-AIRCRAFT STRUCTURES
LOCKHEED-GEORGIA COMPANY CONTRACT CN 36774

Second Quarterly Status Report
December 1, 1976

1. The generally poor fatigue properties displayed by 7XXX aluminum alloys are often attributed to microstructural influences which promote localized deformation during cyclic loading. Conventionally used commerical ingot processing methods for these alloys produce highly elongated and partially-recrystallized grain structures which result in directional properties. Fatigue deformation in such materials is shown to be concentrated in larger recrystallized grains, rather than distributed uniformly throughout the microstructure. The application of intermediate thermomechanical treatments (ITMT) to 7XXX alloys to produce fine, equiaxed grain structures offers the possibility for improving fatigue resistance by eliminating the inhomogeneous fatigue deformation occurring in commercially-processed material. The primary objectives of this research are: (1) To compare the fatigue properties of commercially processed (CP) and ITMT materials, and (2) To examine experimental data in view of proposed theoretical predictions of fatigue crack growth. The alloys being investigated are based on 7050, the new alloy developed by ALCOA for the Navy and Air Force. This alloy combines strength with improved fracture toughness, and stress corrosion resistance.

2. Our initial efforts were summarized in our First Quarterly Status Report, dated September 1, 1976.

Additional low cycle fatigue tests were completed during the past quarter in order to completely describe the Coffin-Manson relationship over the range of strain amplitudes studied. Several additional tests were performed on specially adapted flat-sided specimens in order to metallographically examine the origin of fatigue cracks in the commercially-processed (CP) and ITMT materials. The results of these crack initiation tests showed that cracks initiated almost exclusively at grain boundaries in the ITMT material. In the CP material, crack initiation at slip lines was commonly observed. To determine the origin of this difference in crack initiation behavior, foils for transmission electron microscopy are being prepared. Scanning electron microscopy will also be used to study the origin of fatigue cracking in these samples more carefully.

Tensile testing showed that the yield strengths of the ITMT and CP materials are approximately 84 and 81.5 Ksi respectively. Elongation in a one-inch gage section for both materials is approximately 11 per cent. One sample of each material was pulled to 5% total elongation. Optical metallography was used to examine the surface deformation in both samples. Deformation appeared to be relatively homogeneous for both materials as no slip lines were observed in either sample. However, deformation in the ITMT material appeared to be more uniformly distributed throughout the microstructure. Some grains in the CP sample appeared to be highly deformed while other grains seemed to be practically undeformed. Scanning electron microscopy of tensile fracture surfaces will be performed. Transmission electron microscopy will be performed on the two specimens strained 5% in order to determine if the microscopic homogeneity of deformation is different in the two materials.

Fatigue crack propagation specimens have been machined and polished, and are currently being scribed with grids to facilitate the accurate measurement of fatigue crack growth rates. It is anticipated that most of the planned fatigue crack propagation testing can be completed by the end of December.

Materials for high cycle fatigue specimens have been heat treated and provided to the machine shop for machining. Present plans are for these specimens to be tested sometime during the first quarter of 1977.

Frankford Arsenal has provided another type of 7050 ITMT material which has been hot-rolled after the final recrystallization treatment. Optical metallography has shown that this material has a somewhat elongated grain structure intermediate in grain size between the as-recrystallized ITMT material and the CP material. Low cycle fatigue specimens of this material have been machined and will be tested as soon as machine time becomes available.

3. A formal research proposal has been completed which provides a detailed literature review of the research area and a step-by-step outline of the experimental program now in progress. The proposal has been approved by the Georgia Tech Metallurgy faculty and copies have been provided to Lockheed-Georgia personnel for comment. In addition, a research abstract was prepared and submitted to AIME, for a talk on this research to be presented at the Special Symposium on the Fatigue of Aluminum Alloys, AIME Meeting to be held in Atlanta in March, 1977.

Respectfully submitted,

Edgar A. Starke, Jr.
Professor
Project Director

DOCTORAL RESEARCH PROGRAM-AIRCRAFT STRUCTURES
LOCKHEED-GEORGIA COMPANY CONTRACT CN 36774

Third Quarterly Status Report
March 25, 1977

1. Research accomplished during the past quarter included fatigue crack growth (FCG) measurements, grain size determinations, and transmission and scanning electron microscopy (TEM and SEM) on ITMT and CP 7050. The results of work to date were summarized in a seminar given before Lockheed-Georgia personnel on March 2, 1977 and in a presentation at the 1977 National AIME Meeting on March 9.

2. The main goal of the past quarter's research has been the acquisition of FCG data for the 7050 ITMT-AR and CP material. Plots of FCG rates (da/dN) versus stress intensity range (ΔK) for the experimental materials are shown in Figure 1. The ITMT-AR material showed significantly higher FCG rates at low values of ΔK. SEM was performed on the fracture surfaces of FCG specimens in order to determine the origin of the differences in FCG rates. At low ΔK, fracture surfaces of the ITMT-AR material showed large areas of intergranular fractures and the presence of a large volume fraction of constituent particles. These particles were identified by energy-dispersive x-ray analysis as being extremely rich in copper. The origin of these particles can be determined from an analysis of the processing history of the 7050 ITMT-AR material shown in Table 1. The slow furnace cooling step between 775°F and 500°F allows the precipitation of copper-rich S phase (Al_2CuMg). The subsequent recrystallization step at 850°F is not sufficiently high to redissolve those particles. Thus, as recrystallization occurs, the particles are trapped at grain boundaries. Their presence as intergranular constituent particles serves to weaken the grain boundaries and promote intergranular fracture. The commercial ingot processing history does not allow the occurrence of intergranular S phase since all of the alloying elements (Zn, Mg, Cu) are in solution at the hot-working temperature and rapid cooling is used after deformation.

   It is evident that the improvement of fracture properties (both K_{IC} and FCG resistance) are dependent upon the removal of the copper-rich constituent particles from the microstructure. Conversations with ALCOA have indicated that more effective homogenization steps may redissolve these particles and "clean-up" the microstructure. Work toward this end is presently underway.

3. Grain size measurements were performed on the 7050 ITMT-AR and CP materials as well as a second ITMT material which has been hot-rolled after recrystallization (AR+HR). The results of these measurements, in Table 2, show that the ITMT material, in either the AR or AR+HR condition remains considerably finer in grain size than the CP material.

4. TEM was performed on specimens of both 7050 ITMT-AR and CP material strained 5% in tension. Both materials showed the presence of pronounced dislocation banding within the grains. In most areas where subgrains were observed, deformation appeared to be more homogeneous in nature. In large grains of the CP material and the recrystallized small grains of the ITMT-AR material, the prominent dislocation bands were the probable cause of intergranular fracture observed during SEM of tensile fracture surfaces.

5. Least squares regression analyses were performed for the tensile and LCF data obtained in previous research. The calculated parameters are shown in Table 3.

Respectfully submitted,

Edgar A. Starke, Jr.
Professor
Project Director

TABLE 1

Ingot Processing Schedules of ITMT and CP 7050

ITMT	CP
48 hours 850°F	48 hrs 850°F
Furnace cool to 775°F, hold 5 hrs	Furnace cool to 800°F
Furnace cool to 500°F, hold 4 hrs	
Cold Water Quench	
Reduction @ 525°F	Reduction @ 800°F
48 hrs @ 850°F, CWQ	Air Cool

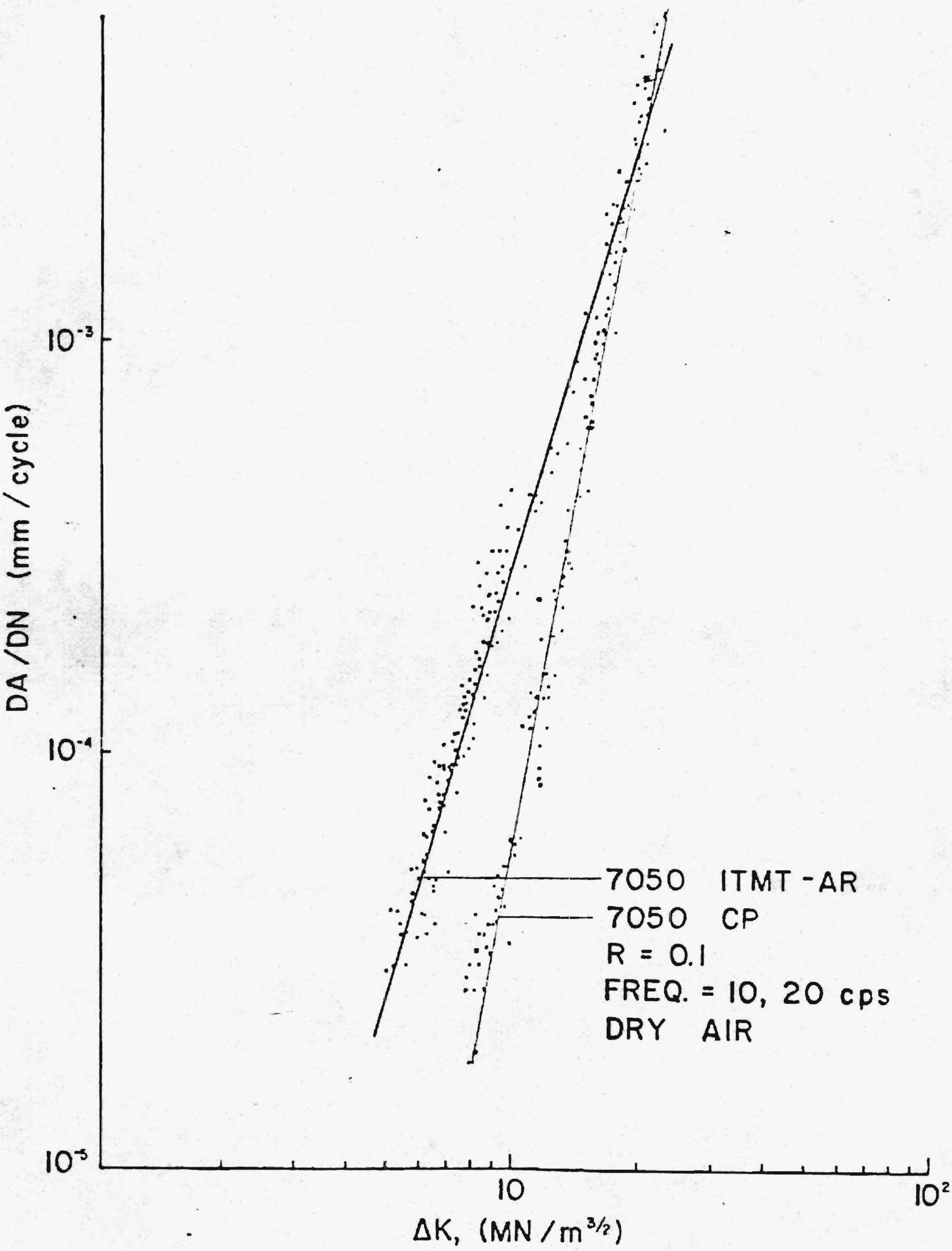

Figure 1. Fatigue crack growth versus stress intensity of ITMT and CP 7050.

TABLE 3

Monotonic and Cyclic Properties

Material	Property - Cyclic		
	n'	c	ε_f' (%)
7050-ITMT-AR	0.05	0.73	126
7050-CP	0.03	0.78	184

Material	Property - Monotonic		
	YS(MN/m)	ε_f (%)	n
7050-ITMT-AR	576.3	10.8	0.04
7050-CP	552.1	11.1	0.05

TABLE 2

Grain Size of 7050 Materials

Material	Average Grain Diameter, mm		
	ST	LT	RD
ITMT-AR	0.018	0.022	0.024
ITMT-AR+HR	0.038	0.058	0.073
CP	0.044	0.102	0.144

PRO

Final Rpt.

E-19-648

THE EFFECT OF INTERMEDIATE THERMOMECHANICAL TREATMENTS ON THE FATIGUE PROPERTIES OF TWO 7XXX ALUMINUM ALLOYS

A THESIS

Presented to

The Faculty of the Division of Graduate Studies

by

Robert Edward Sanders, Jr.

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

in the School of Chemical Engineering

Georgia Institute of Technology

July, 1978

xc: AHB

SLB

THE EFFECT OF INTERMEDIATE THERMOMECHANICAL
TREATMENTS ON THE FATIGUE PROPERTIES
OF TWO 7XXX ALUMINUM ALLOYS

Approved:

Dr. Edgar A. Starke, Jr.
Chairman

Dr. Miroslav Marek

Dr. Pieter Muije

Date approved by Chairman: 8/2/78

SUMMARY

The effect of different ingot processing techniques on the microstructure, monotonic and fatigue properties of 7050 and 7475 aluminum alloys has been investigated. Properties of these alloys after processing by newly-developed intermediate thermomechanical treatments (ITMT) were compared to those of hot-rolled materials which received commercial type processing.

ITMT materials of the two alloys were studied in both the as-recrystallized (AR) and as-recrystallized plus hot-rolled (AR+HR) conditions. Microstructures of the AR variants were highly recrystallized with very fine equiaxed grains. AR+HR materials were partially recrystallized with an elongated pancake-type grain morphology. Hot-rolling of the two alloys, used to simulate commercial processing, produced lamellar, largely unrecrystallized microstructures. The 7050 experimental materials were more fully recrystallized than their 7475 counterparts due to the presence of different dispersoid phases and slight differences in processing conditions.

Hot-rolled variants of the experimental alloys exhibited the best overall combination of fatigue properties of the materials studied. The predominantly unrecrystallized microstructures of hot-rolled 7050 and 7475 promoted a high-energy-absorbing transgranular fracture mode and led to superior resistance to fatigue crack propagation and unstable fracture. The more recrystallized ITMT materials experienced

a higher degree of intergranular fracture which contributed to higher fatigue crack growth rates and lower fracture toughness values. The presence of a large volume fraction of Al_2CuMg in ITMT variants of 7050 was particularly detrimental to the fracture resistance of this alloy.

Total low cycle fatigue and high cycle fatigue lives of the experimental materials were relatively unaffected by changes in microstructure produced by ingot processing. However, quantitative metallography showed that the crack initiation resistance of AR variants was somewhat improved over that of the hot-rolled materials. Crack initiation at slip bands, which occurs extensively in the unrecrystallized hot-rolled microstructure, is severely limited by the fine grain size and random texture produced by AR-type ITMT processing.

The fatigue crack propagation data of the present investigation showed that the presence of residual stresses in un-stretched plate material could markedly affect crack growth rates. A method was suggested to correct for residual stresses in WOL-type specimens and obtain a rough approximation for an "effective" ΔK. Upon the application of this method, the corrected 7475 fatigue crack propagation data was compared to the results of a predictive equation based on low cycle fatigue and microstructural parameters. The relationship correctly predicted the relative order of fatigue crack propagation resistance for the three 7475 experimental materials.